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Communications

A Radio Frequency Identification Implanted in a Tooth can Communicate With the Outside World

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Abstract—A radio frequency identification (RFID) transponder covering the 13.56 MHz band was adapted to minimize its volume so that it could be placed in the pulp chamber of an endodontically treated human tooth. The minimized transponder had a maximum communication distance of 30 mm. In an animal experiment, the transponder was fixed in the cavity of a mandibular canine of a dog. An RFID reader positioned close to the dog's face could communicate with the transponder in the dog's tooth. In certain cases, the system is applicable for the personal identification procedures for hospitalized patients instead of an identification wristband.

Index Terms—Dental treatment, endodontics, inpatient, mobile phone, radio frequency, identification (RFID).

I. INTRODUCTION

Hospitalized patients tend to wear personal identification (ID) wristbands to prevent medical incidents. A radio frequency ID (RFID) tag, holding ID information attached to the wrist band, has been suggested as being useful for the rapid identification of inpatients [1]. However, the continuous wearing of a wristband may induce physical and mental stress in some patients. Dental practice has traditionally adopted various materials for recovering of mastication. Electronic sensor devices, temporarily installed in the oral cavity for physiological research in humans, has already employed [2], [3]. An RFID transponder could be placed in any type of housing, if the performance parameters of the antennae for transmitting and receiving were established. Recent advances in RF technology have decreased the size of RFID transponders less than 1 cm [4], [5], which enable the RFID installation into the endodontic space of the tooth. This led us to develop a new method to prevent medical accidents in hospitals by embedding an RFID transponder in the patient's tooth during dental treatment. This method relieves the patients from the stress of wearing an ID wristband. However, we do not know whether an RFID transponder embedded under these conditions, that is, simultaneously encapsulated with hard tissue (tooth and alveolar bone) and soft tissue (gingival, oral mucosa, and orofacial tissue) of the oral region, is able to communicate with a detector placed beside the patient's face. In this study, we investigated the effects on communication

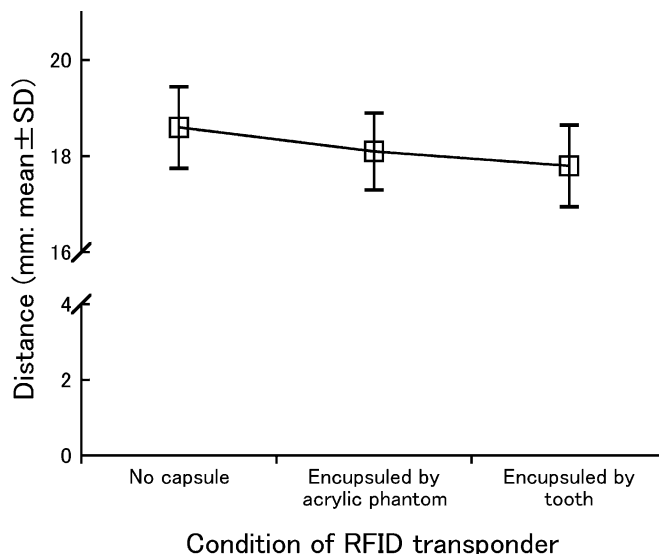


Fig. 1. Communication distance of the RFID transponder to the reader antenna under encapsulated conditions by an acrylic phantom and dentin.

distance of an RFID transponder implanted inside the tooth and the feasibility of an identification method using an RFID installed in the oral cavity.

II. METHODS AND RESULTS

A. Experiment 1: Effects on Communication Distance in the Endodontic Space of a Tooth

Ten extracted human third molar teeth, free from dental caries, were used to encapsulate RFID tags. Fifteen cylindrical tags (o.d., 3 mm; length, 13 mm) using a medium frequency (125 kHz Emfreccia ONMETAL, Mitsubishi Materials, Tokyo, Japan) were tested. The endodontic cavity, including the coronal chamber and root canal of each tooth was prepared to fit the cylindrical core of the RFID tag from the coronal side of the tooth. A dentin thickness of 3 mm was preserved to allow the dentin to function as a barrier for RF between the tag and the reader. Three acrylic cylinders (diameter 10 × 22 mm) in which coaxial holes (diameter, 3 mm; depth, 13 mm) were drilled to place tags were used as controls. An RF reader (Emfreccia, Mitsubishi Materials, Tokyo, Japan) that communicated with the RFID tags enclosed by dentin was located on the extension line of the tooth axis, because these tags had sharp directionality for communication with the reader along the cylindrical shaft direction. The tooth was held with a plastic clamp attached to a carriage, which traveled in the longitudinal axis direction.

The mean communication distance of the unencapsulated RFID tags was 18.6 ± 1.7 mm ($n = 15$), whereas the mean ranges of RFID tags encapsulated with acrylic materials (control) or teeth were 18.1 ± 1.6 mm ($n = 45$) and 17.8 ± 1.7 mm ($n = 150$), respectively (Fig. 1). The ranges of encapsulated RFID tags in acrylic material and teeth compared to those of nonencapsulated RFIDs were $97.3 \pm 1.6\%$ and $94.6 \pm 1.9\%$, respectively. No statistically significant difference under these conditions could be observed.

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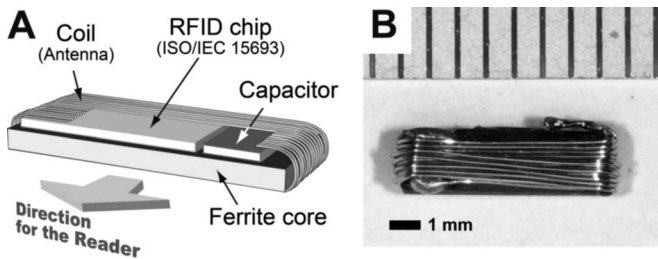


Fig. 2. Components of the RFID transponder. (a) The coil was used as an antenna. An RFID chip and a capacitor were mounted at the base of a ferrite bar. The antenna coil was parallel to the extended shaft of the ferrite bar core and provided directionality to the communication. (b) The transponder was 8 mm \times 3 mm \times 2 mm in size and weighted 0.11 g.

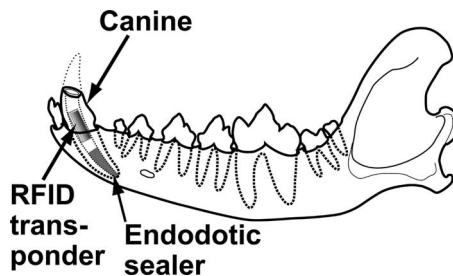


Fig. 3. Positioning of the RFID transponder in the mandibular canine of a beagle dog. After endodontic treatment, a small cavity was made for storing the transponder, which was completely isolated from the surrounding tissues by dental sealing material. The communication direction of the transponder in the tooth cavity was set toward the cheek.

B. Experiment 2: Communication Ability of an RFID Transponder Implanted in a Dog Tooth

A customized RFID transponder was embedded into the canine of a dog (male beagle, weighing 20 kg). This animal experiment was conducted according to the Committee of the Institute of Tohoku University Animal Experimentation. The RFID transponder, fabricated from an ISO/IEC15693 integrated circuit chip (13.56 MHz: SRF55V10S, Infineon Technologies Japan, Tokyo, Japan), was customized into a rectangular bar (Fig. 2) for embedding in the cylindrical endodontic space of a tooth, and spatial directionality was established in communication with a reader positioned beside the dog's face. The pulp of the mandibular right canine was extirpated under general (pentobarbital sodium, 20 mg/kg, i.v.) and local anesthesia (lidocaine 2% with epinephrine 1:80 000). The apex portion of the root canal of the canine was filled with endodontic sealer (Calcipex, Nippon Shika Yakuhin Company, Ltd., Shimonoseki, Japan). The transponder was sealed and fixed with epoxy resin [2] in the residual cavity of the canine after endodontic treatment (Fig. 3). A conventional hand-held reader (ID.ISC.PRH: ISO/IEC15693, 500 mW, Feig, Weilburg, Germany) was used for the communication test with the embedded transponder in the canine.

The communication range of the transponder without the barrier of orofacial biotissue before installation in the canine was 30 mm. The signal of the transponder could be detected when the reader was brought close to the cheek. The communication distance between the reader and the embedded transponder in the canine was estimated to be 25 mm. The embedded transponder in the dog ceased to respond a few days after installation; however, the recipient dog has remained healthy with the transponder in its canine for more than 1 year.

III. DISCUSSION AND CONCLUSION

The electrical signals of medium-frequency and high-frequency (HF) bands pass through the cutaneous layer without significant attenuation. This characteristic of RFs has been used to drive active implantable medical devices (AIMDs), such as cochlear implants [6] and cardiac pacemakers [7]. We expected that the dentin could shield RF waves, because electron density and electrical impedance are relatively high in such human biotissue. The decrease in communication distance under encapsulated conditions with the tooth dentin was only 5.4% (experiment 1), suggesting that the hard tissues of the teeth could not work as a barrier to radio waves of the medium-frequency band. The HF RFID transponder inside the multilayer structure composing hard tissues and soft tissues could communicate with an outside reader (experiment 2). The RFID transponder having the size and shape of a credit card is expected to communicate with the reader up to a distance of 10–70 cm according to the ISO/IEC 15693 standard [8]. The communication distance in this experiment was less than the distance for standard applications, because the antenna of our customized transponder was smaller than that of the standard equipment.

Possible physical and mental burdens would result from the installation of artificial devices in the human body. The methods to decrease the psychological burden on recipients of implanted RFIDs, such as placing the detector close to the embedded position in the face should be developed. The present method of locating the RFID in the oral cavity has two remarkable characteristics. First, in dental treatment, widely used materials include metal, plastic, and porcelain. An RFID transponder can be encapsulated in a tooth using these materials and positioned in the human oral cavity for long periods. Furthermore, patients with RFID transponders can remove or replace them noninvasively during common dental procedures. Second, the RFID can be embedded in the oral cavity so that it is nearly invisible. If an RFID reader was built into the handset of a telephone or a mobile phone [9], the communication process with the RFID in the tooth would be difficult to distinguish from the recipient's talking on a telephone. A recipient with an RFID embedded in a tooth would have little physical or mental stress.

We employed a passive RFID device that required a low-level electromagnetic field on the HF wavelength, which is traditionally used for AIMD. It has well established that the low-level electromagnetic fields of microwaves generated by mobile phones showed the biological effects [10], whereas only a few reports have been published about the effect of low-level HF radio waves [11]. The risk of harmful effects of the HF low-level electromagnetic induction is extremely low [5].

In our dog experiment, the lifetime of the customized transponder after installation in the living animal was only a few days, possibly because the transponder was insufficiently waterproof, or because strong occlusal forces destroyed the RFID circuit. Durability must be improved before this system is practically applied. Current implantable apparatuses such as AIMDs include various sensors for monitoring hemodynamics and ventilation rate to detect physiologic changes [12]. If RFID technology acquires various functions of physiological sensing and stimulation, implantable RFID transponders will develop into devices for patient safety and for the maintenance of health.

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